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The influence of physical conditioning on tolerance to a centrifugation profile called the Simulated Aerial Combat Maneuvering (SACM)--was determined using 24 young men as subjects. These subjects were assigned to groups as controls (C: no physical training), runners (R), and weight trainers (W) and followed a 12-week protocol of specified physical training. During this study, tolerance to the SACM, maximum oxygen consumption, muscle strength, and body composition were periodically determined. SACM tolerance was defined as the total time that a subject could withstand continuous exposure to a 4.5 and 7.0 $+G_z$ centrifugation

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20. ABSTRACT (Continued)

profile as determined by his voluntary endpoint of fatigue. The $+G_z$ tolerance of the runners and controls increased at an average rate of 4 s per week during the course of the experiment. On the other hand, the weight trainers increased their G tolerance at an average rate of 15 s per week. The difference between group W and groups C and R was statistically significant at the 5% level. Fatigue scores indicate that group W subjects took longer to reach a given level of fatigue than did subjects of the other groups. Therefore, a physical conditioning program of weight training will apparently improve human tolerance to aerial combat maneuvers.

The Influence of Differential Physical Conditioning Regimens on Simulated Aerial Combat Maneuvering Tolerance

W. L. EPPERSON, R. R. BURTON, and E. M. BERNAUER

Eglin Air Force Base, Florida 32542; USAF, School of Aerospace Medicine, Brooks Air Force Base, Texas 78235; and Physical Education Department, University of California, Davis, California 95616.

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IN RECENT YEARS, high performance fighter aircraft (F-14, F-15, F-16, F-18, and A-10) have generated interest in the ability of the aircrewmember to perform in the maneuvering high-G environment that these aircraft are designed to sustain. Pilots of aircraft flying in the high-G environment appear to suffer from G fatigue and are therefore interested in ways to alleviate this condition (6).

Individuals exposed to the high-G environment must perform an M-1 straining maneuver in order to resist the effects of G (4). Since the M-1 is a very physical activity, it by itself can be extremely fatigueing, and is probably a major contributor to G fatigue.

The broad physiologic effects of acceleration are reasonably well understood, particularly in dealing with the relaxed individual (4,8,9). On the other hand, less is known about the physiologic events and adjustments which occur with high levels of acceleration, and of the physiologic basis of methods used to alter acceleration tolerance.

Over the years the influence of physical fitness and related parameters on G-tolerance have been considered by several investigators (7,13,15,26,27). Physical training, appears to have little effect on relaxed G tolerance. However, unlike relaxed G tolerance, straining G tolerance—which relates specifically to fighter pilots—may be improved by physical training. At this time however, it is not clear which training regimens are effective and how much training is necessary to improve this type of G tolerance.

METHODS AND MATERIALS

The basic experimental design was that of a longitudinal study of the effects of two different physical conditioning programs: a) a dynamic, moderate intensity

The research reported in this paper was conducted by personnel of the Crew Technology Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, USAF, Brooks AFB, Texas 78235. The contents of this paper have been included in a dissertation as partial fulfillment of the requirements for the degree of Doctor of Philosophy at the University of California, Davis, California.

The voluntary informed consent of the subjects used in this research was obtained in accordance with AFR 169-3.

and moderate duration training program which consisted of a combination of long distance continuous running and short distance interval running and (b) a static, high intensity and low duration training program of circuits of specified weight training exercises.

Subject Selection: Volunteer subjects were recruited from airman who had just completed Basic Military Training at Lackland Air Force Base, Texas. After the volunteers had passed a Class II Flying Physical Examination, they were given an indoctrination ride on the USAF School of Aerospace Medicine human centrifuge, and thirty subjects were selected for the study.

G Training: Five weeks were devoted to training the subjects to tolerate the SACM type of G exposure to their maximum capability and to familiarize them with the treadmill and all other experimental procedures. During this time period, each subject was given six training exposures on the centrifuge. During the 5-week training period all subjects were instructed not to engage in regular or strenuous physical activity. At the end of the centrifuge training period the subjects were divided into the experimental/training categories of Controls (no exercise; C), Runners (R), and Weight Trainers (W). Each training category was balanced for SACM tolerances, physical fitness, and physical characteristics. For various medical and personal reasons, the number of subjects to complete the experiment in each exercise category were controls - 9, Runners - 8, and Weight Trainers - 7. Consequently, throughout this report, only data were used for those subjects who completed the study. The physical characteristics and specific groupings of the individual subjects are shown in Table I.

Running Training: The running training program was intended to significantly improve the subject's tolerance to moderately intense, long duration work as measured by maximum aerobic capacity ($\dot{V}O_2$ max). The training program included two out-of-doors workouts each day; one in the morning, devoted to continuous running up to 6 mi, and the other, after lunch, was used for paced interval running. The environmental temperature for the runners ranged from a low of 19°C in the morning at the beginning of the study (April) to a high of 36°C in the afternoon at the end of the study (July). At no time was the runner's training interrupted because of elevated ambient temperatures. A combination of continuous running over a measured course and paced intervals (on a 440 yd track) was used, either of which can effectively enhance $\dot{V}O_2$ max (25). During inclement weather or for specific subject problems such as shin splints, training sessions were performed on the treadmill or on a electrically braked bicycle ergometer.

Weight Training: The weight trainers worked out in a ventilated gymnasium once each day in the morning. Although the gymnasium was not air-conditioned, the

TABLE I. PHYSICAL CHARACTERISTICS OF THE EXPERIMENTAL SUBJECTS, IDENTIFICATION NUMBER, EXERCISE CATEGORY, AND G TOLERANCE (SEC) ATTAINED THROUGH SACM TRAINING ARE SHOWN FOR THE THREE EXPERIMENTAL GROUPS (MEANS ± S. E.)

Subject Number	Exercise[a] Category	Age (Yrs)	Height (Cm)	Body Mass (Kg)	SACM Tolerance (Sec)
Group I (week 1)[b]					
01	C	20	162	58	413
11	R	18	165	58	364
21	W	20	175	78	189
02	C	18	181	79	107
12	R	19	182	68	104
22	W	18	172	65	147
23	W	19	178	60	183
03	C	18	170	68	284
13	R	18	178	66	233
($\bar{x}$ ± S.E.)		18.7±0.3	174±2	66.7±2.6	225±37
Group II (week 2)					
24	W	18	177	73	157
04	C	18	172	77	204
15	R	21	167	64	149
25	W	20	181	80	384
05	C	19	178	62	111
16	R	18	172	73	162
17	R	18	171	60	96
($\bar{x}$ ± S.E.)		18.9±0.5	174±2	69.9±3.0	180±37
Group III (week 3)					
06	C	19	184	69	226
18	R	21	192	89	146
27	W	18	178	71	276
28	W	18	176	71	289
07	C	28	176	62	134
19	R	21	176	72	186
08	C	21	178	70	117
09	C	22	171	65	155
($\bar{x}$ ± S.E.)		21.0±1.1	179±2	71.1±2.8	191±23

[a]C = control (no exercise; R = runners; and W = weight trainers.
[b]Grouped for logistical purposes. Each group had 10 subjects at the beginning of the study.

ambient temperature in the morning during their workouts for the entire study never exceeded 27°C. The equipment used for weight training included a Universal Gym, (Universal Gym Products, 17352 Von Karmon, Irvine, CA 92714) wall mounted pulley weights, dumbbells, barbells, benches, and boards.

Two circuits of common exercises (10,17,22) were specified for training (Table II). Each circuit was used every other day so that a two day cycle would exercise all major muscle groups. To complete a circuit each exercise was performed for three sets with a 3-min rest between sets (2).

TABLE II. SPECIFIC MUSCLE TRAINING CIRCUITS USED BY THE WEIGHT TRAINING GROUP.

Circuit 1	Circuit 2
1. Arm curl	1. Sit up
2. Standing press	2. Heel rise
3. Wrist roller	3. Head strap
4. Lat. pull down	4. Leg press
5. Bench press	5. Side-to-side bend
6. Erect row	6. Bent leg dead lift
7. Dumbell high pull up	

During the first training session, the 1 rep maximum (1RM) weight was determined for each of the lifting motions. During the second training session, set 1 was for 10 reps using 70% of the 1RM weight. Sets 2 and 3 used 80% of the 1RM weight with a limit of 10 reps in each set. The weight remained constant until the subject could complete 10 reps on set 3. When this occurred, the subject would add 5 lb to the "80%" weight for upper body motions, and 10 lb for lower body motions for the next training session. Appropriate amounts were added to the "70%" weight to maintain its relative level. These weights would be used until the subject once again could complete 10 reps on set 3. This regimen continued for the entire training program.

Two weight lifting exercises differed from the others in their training application. The wrist roller was used only for one repetition (not 10 repetitions) for each set; the weight used on the head strap was only 50% of 1RM—a precaution to avoid neck injury. For the sit up, a level board was used with the weight held either behind the neck or on the chest. The weight used in all training sessions was recorded in order to follow the individual subject's progress in gaining strength.

Controls: The control subjects were not permitted to participate in any kind of regular physical activity or training program. They were assigned as training monitors and record keepers for the physical conditioning programs. In this capacity they were exposed to the same environmental conditions as the subjects in the exercise groups.

Environmental and Living Conditions: All subjects shared the same living accomodations in non-airconditioned barracks at Lackland AFB, Texas, and were bussed to and from Brooks AFB, Texas each duty day. Throughout the study the subjects' off-duty time was not controlled except for minor specific restrictions regarding food, drink, and sleep the night before and the day of data collection.

Measurements of Physical Fitness

Aerobic Capacity: Maximum oxygen consumption ($\dot{V}O_2$ max) was determined on all subjects at weeks 1, 4, 8, and 12 of the study. This determination was made on a motor driven treadmill using a multistage branching treadmill test developed at the Human Performance Laboratory, University of California at Davis.

Physiologic measurements were taken continuously during the treadmill test, from 2 min pre-walk (subject standing) through a 2 min post-walk recovery. Expired air composition was determined by a Perkin-Elmer Model 1100 Medical Gas analyzer. Percentages of O_2 and CO_2 were recorded in tabular form every 15 s during the test. In addition, expired gas volume (from the output of a Parkinson-Cowen gasometer), O_2 and CO_2 percentages (from the Medical Gas Analyzer), and heart rate (from a cardiotachometer) were recorded on a strip chart (Brush 440 Recorder). Treadmill speed and elevation, and inlet and outlet temperatures of the gasometer—as measured by Telethermometer—were all annotated on the strip chart recorder at regular intervals. The $\dot{V}O_2$ max was used to evaluate aerobic fitness of all of the subjects engaged in the study.

Total blood volume was determined for all subjects during weeks 1, 8, and 12 using CO rebreathing techniques (18). Since it is well established that blood volume increases with running training (11,20) and hot climatic conditions (14,24), changes in blood volume during the training program also were used to estimate aerobic conditioning.

During the entire running program, each subject recorded all distances run and the times to complete each distance for each training session. From these records, the total miles trained on a weekly basis also became useful as an indicator of aerobic capacity.

Muscular Strength: Muscular strength of the weight trainers as determined by recording the training weight for four major exercising muscle groups—arms, chest, abdomen, and legs. These weight lifting motions were the arm curl, bench press, sit up, and leg press respectively. These muscle groups are representative of the major muscular functions which would appear to be most useful in performing the M-1. To quantify muscular strength, throughout the study, the "80%" training weight value was most useful.

G-Tolerance: Acceleration tolerance was determined using the USAF School of Aerospace Medicine human centrifuge (4). The subject, fitted with an anti-G suit (USAF CSU-12/P), was positioned in an aircraft seat (13° seatback angle) in the gondola of the centrifuge. During G exposure the anti-G suit was inflated at 1.5 psi/G beginning at 2G. The subject was monitored using two ECG channels, an ear oximeter for continuous measurement of arterial saturation (3), closed circuit television, and two way audio communication. A medical monitor and a central observer in the control room observed the subject at all times during a centrifuge run. For details regarding human exposure procedures to acceleration the reader is referred to Shaffstall and Burton (23).

Before the SACM tolerance run to fatigue was made, the subject was exposed to 30 s of 3G to check out the medical monitoring equipment, anti-G suit inflation, and to stimulate his cardiovascular system.

The SACM tolerance consisted of alternating 15 s

TABLE III. THE EFFECTS OF PHYSICAL TRAINING FOR 12 WEEKS ON SEVERAL PHYSICAL AND PHYSIOLOGICAL PARAMETERS IS COMPARED BETWEEN WEEK 1 (PRE; BASELINE) AND WEEK 12 (POST) USING PAIRED t-TESTING. SHOWN ARE GROUP MEANS ±S.E. AND % CHANGE IN THE PARAMETER RESULTING FROM THE TRAINING PROGRAM.

	Controls (Group C)				Runners (Group R)				Weight Trainers (Group W)			
Parameter	Pre[a]	Post[a]	%Δ[b]	p[c]	Pre	Post	%Δ	p	Pre	Post	%Δ	p
Body Mass	67.8 ±2.5	67.9 2.4	0.2	NS	69.0 3.3	68.5 3.3	−0.7	NS	69.6 2.7	71.2 2.9	2.3	<0.01
$\dot{V}O_2$ max	47.3 1.4	46.7 1.5	−1.3	NS	49.2 1.0	52.9 1.4	7.5	<0.05	47.7 1.5	47.0 2.1	−1.5	NS
Blood Vol	6.06 0.22	6.08 0.26	0.3	NS	5.77 0.19	6.20 0.18	7.5	<0.01	5.66 0.22	6.05 0.20	6.9	NS
$+G_Z$ Tol	195 34	242 39	24.1	NS	180 31	226 33	25.5	NS	232 33	411 67	77.2	<0.05

a: Mean ± S.E.; Pre = Baseline (week 1); Post = End of Training (week 12); Body mass in Kg; VO_2 max in $ml \cdot min^{-1} \cdot kg^{-1}$; Blood Vol in liters; G Tol (SCAM) in sec.
b: [(Post-Pre)/Pre] X 100 = %Δ
c: Paired t-test; NS = not significant, $p > 0.05$.

plateaus of 4.5 and 7.0 G continuously until each subject's voluntary endpoint of fatigue was reached. Upon reaching his point of fatigue, the subject stopped the centrifuge by releasing the brake held in his left hand. A subject's tolerance time was defined as the time spent continuously at a G load greater than 2 G. Details regarding this type of G-tolerance determination are available to the reader (5). Tolerance to the SACM profile was measured on weeks 1, 3, 4, 6, 8, 10, and 12 of the protocol.

At week 11, each subject was exposed to the SACM profile for a duration equal to their SACM tolerance time determined in week 1 (base-line). This allowed for data, derived from the same SACM exposure time to be compared between the same subjects—untrained and physically trained.

The fatigue status of each subject relative to an SACM exposure was subjectively determined using the fatigue score list developed at USAFSAM (21). A fatigue score was determined for each subject immediately before and after the SACM and 20 min after the SACM. A comparison of fatigue scores between those immediately before with those immediately after estimated the amount of fatigue caused by the SACM exposure. The fatigue score determined 20 min after the end of the SACM exposure measured the degree of recovery from the SACM fatigue.

RESULTS

Since the object of this study was to determine the total 12-week effect of two different physical training programs, the data for weeks 1 and 12 of the study were compared. The first week served as the base-line condition and the last week of the study measured their final physical condition. If signficant differences existed regarding the effects of the physical conditioning program, then these would be most apparent comparing the parameters of the individuals at the beginning of the study with those measured at the end of the study when the greatest effect of training had occurred. These data were statistically compared by paired t-testing and summarized as group means ±S.E. in Table III.

Over the 3-mo physical conditioning period, the weight trainers increased their body mass by 1.6 kg, whereas neither the controls nor the runners recorded a significant change in body mass. This finding is expected since it indicates that the subject groups were metabolically in a relatively steady state except that the weight trainers were building muscle as a result of the training program.

Muscular Strength: Strength measurements were considered for four major lifting motions because these corresponded to the major muscle (body) groups described. These measurements were determined only for the weight trainers and are shown in Table IV.

The weight training group were of average strength for their age when the program began. Their week 1 1RM bench press averaged 125 pounds, which is similar to the initial strength published elsewhere for 177 college freshman (2).

TABLE IV: THE EFFECTS OF PHYSICAL TRAINING FOR 12 WEEKS ON STRENGTH IS COMPARED BETWEEN WEEK 1 (PRE; BASELINE) AND WEEK 12 (POST) USING PAIRED t-TESTING. STRENGTH COMPARISON WAS MADE FOR ONLY THE WEIGHT TRAINERS. SHOWN ARE GROUP MEANS ±S.E. AND % CHANGES IN THE PARAMETER RESULTING FROM THE TRAINING PROGRAM.

Weight Trainer's Strength									
	Pre[a]	Post[a]	%Δ[b]	p[c]		Pre	Post	Δ%	P
Arm Curl	60.0 4.63	75.7 3.69	26.2	<0.01	Bench Press	102.9 8.08	130.0 11.95	26.3	<0.05
Leg Press	282.1 18.25	402.9 25.47	42.8	<0.01	Sit up	30.6 3.50	60.9 7.79	99.0	<0.01

a: Mean ±S.E.; Pre = Baseline (week 1); Post = End of Training (week 12), strength is in pounds; b: [(Post - Pre)/Pre] X 100 = %; c: Paired t-test; NS = not significant, $p>0.05$.

The increase in muscle strength was statistically significant (paired *t*-test) for all four motions. These increases in strength ranged from 26% for the bench-press and arm-curl to nearly 100% for the sit-up.

The changes in strength for the weight trainers for the sit-up and arm-curl were consistent during the course of the study (weeks 1, 4, 8, and 12), thus resulting in significant correlation coefficients ($p<0.01$) and the following regressions:

$$S = 30.4 + 3.32\,t \quad \text{(Eq. 1)}$$
$$A = 61.6 + 1.74\,t \quad \text{(Eq. 2)}$$

where S = sit-up weights (lbs); A = arm-curl weights (lbs); and t = time in weeks. Although the initial weight for the sit-up (30.4, eq. 1; 13.8 kg) was approximately 50% those of the arm-curl (61.6, eq. 2; 28.0 kg), the increase in strength (lb/week) was twice as great for the sit-up (3.32 lb/week or 1.51 kg/week) as for the arm-curl (1.74 lb/week or 0.79 kg/week). Consequently, at the end of the study the final weights being used for each motion were quite similar; i.e., 60.9 lb (27.7 kg) for sit-ups and 75.7 lb (34.4 kg) for the arm-curl (Table IV). Although the trained-strength capacity of the biceps and abdominal muscles are quantitatively similar, the untrained strength of the biceps is twice that of the abdominals; so the abdominal muscles are apparently used much less on a routine daily basis.

Aerobic Capacity: The degree of aerobic fitness, as measured by $\dot{V}O_2$ max, of each subject was determined four times during the study—weeks 1, 4, 8, and 12. These results, presented in Table III, indicate that the running group increased their aerobic fitness by 7.5% as a result of the running training whereas groups C and W recorded nonsignificant decreases in $\dot{V}O_2$ max. The changes in $\dot{V}O_2$ max are within the expected range considering the type of training programs engaged in by each of the experimental groups.

The initial $\dot{V}O_2$ max for an individual subject had a range of 42.2 – 55.1 ml/min/kg body mass which indicates that all of the subjects were in average to above average aerobic condition (1,12). Since our subjects had recently completed USAF Basic Military Training, their good condition is not surprising. At the end of this study (week 12) the range in $\dot{V}O_2$ max for the individual runner was 47.7 - 58.4 ml/min/kg body mass which indicates the excellent aerobic physical condition of this trained running group.

The $\dot{V}O_2$ max changes with time for the entire study were calculated using correlation coefficients and regression analyses for the three training groups using data from weeks 1, 4, 8, and 12 (Table V). Although a statistical increase in $\dot{V}O_2$ max occurred only in group R (paired *t*-test; first week compared with week 12, Table III), all three exercise groups had significant correlation coefficients with time.

Group R had an increase in $\dot{V}O_2$ max by an average of nearly 1% per week whereas groups C and W recorded slight yet consistent decreases. Groups C and W were probably deconditioning from the aerobic fitness levels achieved in Basic Military Training—the type of physical activity engaged in by group W was not adequate to prevent some aerobic deconditioning.

For group R, the greater rate of change of $\dot{V}O_2$ max was determined by regression (1%/week) over that indicated by comparing pre- and post- values (Table III) results from the direct close relationship of $\dot{V}O_2$ max with the intensity of training. Generally, the mileage each subject ran increased each week through week 9 then decreased during the last 3 weeks. Likewise the average $\dot{V}O_2$ max increased from week 1 through week 8 and then decreased at week 12 (week 8 = 54.0, week 12 = 52.9 ml/min/kg body mass).

Blood Volumes: Another indication of the effects of the training programs is reflected in the changes in blood volume shown in Tables III and V. Only the runners had a significant increase (paired *t*-test) in blood volume during the course of the study. Group R recorded a 7.5% increase between the pre- and post-training measurements (Table III) and about a 1% increase in blood volume per week using regression analysis (Table V). Blood volume changes were qualitatively similar to those of $\dot{V}O_2$ max relative to the intensity of training. The weekly blood volume change from week 1 to week 8 was 60 ml/week while there was a smaller weekly increase of 27 ml/week from week 8 to week 12. This increase in blood volume in the runners was to be expected for subjects engaged in an aerobic conditioning program (1,11,20).

Interestingly, the weight trainers recorded a nonsignificant yet substantial increase in blood volume that was not entirely unexpected—group W had an individual subject average increase of about 400 ml (6.9%) in blood volume during the 12 week study (Table III). An increase in blood volume associated with weight training has been reported previously but the exact relationship is not completely clear at this time. Three conditions in our study could possibly have contributed to the change in blood volume for the weight trainers: a) the weight training program per se; b) aerobic deconditioning (1,16); and, c) an increase in environmental temperature during the course of the study (14,24) (average daily maximum and minimum centigrade temperatures were respectively 23.3° and 15.0° for mid-April; and 33.9° and 22.8° near the end of June).

Group C did not have a change in blood volume.

TABLE V. REGRESSION ANALYSES FOR $\dot{V}O_2$ MAX, BLOOD VOLUME, AND SACM TOLERANCE RELATIVE TO WEEKS OF TRAINING—$y = a \pm bt$, WHERE y = PARAMETER AS A FUNCTION OF t (WEEKS) WITH a AS THE INTERCEPT AND b THE SLOPE (RATE OF CHANGE).

	$\dot{V}O_2$ max[a]			BLOOD Volume[a]			SACM Tolerance[a]		
GROUP	a[b]	b[b]	p[c]	a[b]	b[b]	p[c]	a[b]	b[b]	p[c]
C	47.3	−0.037	<0.05	6.06	1.42	NS	181	4.3	<0.01
R	49.2	0.452	<0.01	5.84	57.89	<0.01	173	4.2	<0.01
W	47.2	−0.028	<0.05	5.93	34.88	<0.05	217	15.6	<0.01

a: $\dot{V}O_2$ max in ml·min-1; % blood volume in L; and SACM tolerance[a] in sec.
b: $y = a \pm bt$ where y = parameters as a function of the week 1 intercept (a) ± rate of change (b) per week (t).
c: p = probability of chance occurrance.

However this group was also exposed to two conditions similar to the weight trainers which have been proposed as possibly contributing to the change in blood volume in Group W, namely aerobic deconditioning and an increase in environmental temperature. Therefore weight training appears to be a critical factor in the increase in blood volumes of the subjects in group W.

G Tolerance: All subjects had their SACM tolerance times determined on weeks 1, 3, 4. 6, 8, 10 and 12 of this study. As with the physical training parameters, these SACM tolerances data were statistically analysed using paired *t*-testing between week 1 and week 12. These SACM tolerance evaluations are presented in Table III. A significant increase (paired *t*-test) in tolerance times for the weight trainers was found. The SACM tolerance increases for groups C and R were small (about a 25% increase) and were not statistically significant. These small increases in tolerance times for groups C and R suggest that repeated exposure to SACM over several weeks time may provide a learning experience. For all groups there was no evidence of any plateauing of tolerance times near the end of the experiment. A statistical comparison (student's *t*-test) of SACM tolerance means for week 1 between groups C, R, and W found no significant differences. However, at week 12, group W had a significantly higher tolerance time mean than groups C and R ($p<0.05$).

The rate of change of G tolerances for each experimental group was determined using correlation coefficients and regression analyses for weeks 1, 3, 4, 6, 8, 10, and 12 (Table V). Regression analysis for group W indicated that the weight trainers increased their SACM tolerance time by over 15 s/week. By contrast, groups C and R indicated a significant increase in tolerance time of just over 4 s/week. As suggested earlier, tolerance time changes demonstrated by groups C and R suggest a learning effect—probably indicating that the subjects improved their M-1 skills during the course of the study. A statistical comparison of the average tolerance time slopes of each group found that group W had a significantly greater rate of SACM tolerance time increase than either the controls or the runners ($p<0.05$).

The average fatigue scores for each experimental group for weeks 1, 11, and 12 are presented for comparison in Table VI. The immediate post-G fatigue scores were significantly lower ($p<0.05$) than the pre-G scores except for group W, week 11. Each group's fatigue scores for pre, post 1 and post 2 for weeks 1, 11, and 12 were also statistically analyzed (analysis of variance). Group W post 1 data were significantly different when these data (post 1 of weeks 1, 11 and 12) were compared by pairing *t*-testing—group W was not as fatigued after the week 11 G-exposure as they were after the week 1 exposure of the same duration SACM.

DISCUSSION

The present study was designed to determine if a program of a specific type of physical conditioning could improve a pilot's ability to tolerate the acceleration ($+G_z$) stress associated with the air combat maneuvering (ACM) environment. To this end, two physiologically and physically different training programs were studied to determine their importance in altering ACM tolerance.

A significant portion of this combat environment involves high G maneuvering necessary to avoid or attack any potential threat. Consequently, acceleration forces add a significant physical and physiological stress to the pilot's total workload during the ACM. In the present flying environment, pilots are reported to be very fatigued; also several episodes of loss of consciousness during G maneuvers have occurred (19).

If exposure to high G was limited to less than 10 s followed by a prolonged period (30 to 45 s) of rest at low to moderate G, then a single near-maximal M-1 would be adequate for the pilot to remain functional. In the past, this type of limited high G ACM was typical because aircraft were not capable of sustaining high G loads without losing energy (airspeed or altitude) which had to be gained back before another high G exposure could be achieved (thrust available was much less than thrust required in a high G situation).

However, today's high performance aircraft with their lower wing loading and more fuel-efficient high-thrust engines are capable of sustaining up to 9 G for prolonged periods of time. With this capability, the ACM is composed of repeated episodes of high sustained G, in which the pilot must be capable of functioning.

The G profile used in this study was designed to have

TABLE VI. FATIGUE SCORES AND SACM TOLERANCE TIMES (GROUP MEANS ±S.E.) ARE SHOWN FOR EXPERIMENTAL WEEKS 1, 11, AND 12. A HIGH FATIGUE SCORE INDICATES LOW FATIGUE (21).

	Fatigue Scores											
	Week 1			Week 11			Week 12			SACM Tolerance[b] (s)		
Group	Pre	Post 1[a]	Post 2[a]	Pre	Post 1	Post 2	Pre	Post 1	Post 2	Week 1	Week 11	Week 12
C	14.8	8.6	11.6	15.1	8.1	12.0	15.1	6.2	12.2	195	179	242
	±0.81	0.84	0.84	0.66	1.19	0.98	0.45	0.62	1.20	34	37	39
R	15.0	8.7	11.4	12.4	9.1	11.9	14.1	8.3	11.1	180	164	226
	±1.00	1.64	0.95	1.29	1.08	1.30	1.55	1.34	1.32	31	20	33
W	16.7	8.0	12.1	15.7	12.3[c]	13.2	15.7	8.8	14.0	232	232	411
	±1.17	1.50	1.32	1.33	1.63	1.58	0.80	2.10	1.41	33	40	67

a: Post 1 is immediately after G exposure; Post 2 is 20 min after G exposure.

b: SACM exposure for week 11 was specified to be the same as for week 1. In some cases the members of groups C and R were unable to accomplish week 1 tolerance times. Tolerance times for week 1 and 12 are the same as shown in Table III and are shown here only for comparative purposes.

c: The Pre, Post 1 and Post 2 values for each group for weeks 1, 11, and 12 respectively were statistically analyzed by analysis of variance. For group W Post 1 (immediately post G), the value of $F2/12 = 4.385$ was significant at $p < 0.05$. Further analyses by paired *t* analysis indicated that week 11 fatigue scores were significantly higher ($p < 0.05$) than week 1 scores.

the general characteristic of the inflight ACM environment.

The profile of alternating 15 s plateaus of high and low G with rapid changes between plateaus was developed because it has all of the basic characteristics of an actual ACM, and measuring the time to fatigue that each subject achieved made the test quantifiable. The high G plateau of 7 G is a G load where the subject must perform an M-1. The 15 s plateau is long enough that three to five cycles of the M-1 are required by the subject during the plateau. The 4.5 G plateau allowed the subject a period of rest—not fully relaxed, yet leg tensing alone with the anti-G suit, but without the M-1, was sufficient to tolerate the G load. Also while at 4.5 G the subject is sufficiently active so as to be prepared for the onset of the next 7 G plateau (5).

An indication of the validity of fatigue as a valid criterion, repeatedly recognized by the subject, is the similarity of fatigue scores of the 3 experimental groups at weeks 1 and 12. Also, weight-trained individuals clearly demonstrated a reduction in fatigue under similar workloads; i.e., in week 11, the weight-trained subjects completed the same duration of SACM they had accomplished in week 1 with significantly less fatigue (Table VI). Recently, the fatigue end point of the SACM has been additionally validated using heart rate recovery, various seat back angles, and repeated SACM exposures (5). This SACM profile is routinely used at the USAF School of Aerospace Medicine and has been found to be of value in measuring anti-G methods and equipment (5,23).

The findings in this study, that weight training can significantly improve SACM tolerance, are of considerable importance to the fighter pilot of today's high performance aircraft. This experiment has identified a way by which pilots will be able to more easily tolerate the ACM environment. Since the pilot will be less fatigued, he should be able to direct more effort towards mission performance. Also, a conditioned pilot will be able to press an ACM engagement longer and at a more intense level—improving his changes of success and survival.

REFERENCES

1. Astrand, P., and K. Rodahl. Textbook of Work Physiology. McGraw-Hill; 1970.
2. Berger, R. Effect of varied weight training programs on strength. *Res. Quart.* 33:168-181, 1962.
3. Besch, E. L., F. W. Baumgardner, R. R. Burton, K. E. Gillingham, R. F. McPherson, and S. D. Leverett, Jr. Calibration of a new ear oximeter in humans during exposure to centrifugation. *J. Appl. Physiol.* 44:483-487, 1978.
4. Burton, R. R., S. D. Leverett, Jr., and E. D. Michaelson. Man at high sustained $+G_z$ acceleration: A review. *Aerospace Med.* 45:1115-1136, 1974.
5. Burton, R. R., and R. M. Shaffstall. Human tolerance to aerial combat maneuvers. *Aviat. Space Environ. Med.* 51:641-648, 1980.
6. Burton, R. R., W. F. Storm, L. W. Johnson, and S. D. Leverett, Jr. Stress responses of pilots flying high-performance aircraft during aerial combat maneuvers. *Aviat. Space Environ. Med.* 48:301-307, 1977.
7. Cooper, K. H., and S. D. Leverett, Jr. Physical conditioning versus $+G_z$ tolerance. *Aerospace Med.* 37:462-465, 1966.
8. Fraser, T. M. Human response to sustained acceleration; NASA-SP-103, Washington, DC, 1966.
9. Gillies, J. A. (Ed). *A Textbook of Aviation Physiology.* Pergamon Press; 1965.
10. Hoffman, B. Weight Training for Athletes. The Ronald Press Co.; 1961.
11. Holmgren, A., F. Mossfeldt, T. S. Jostrand, and G. Strom. Effect of training on work capacity, total hemoglobin, blood volume, heart volume and pulse rate in recumbent and upright positions. *Acta Physiol. Scand.* 50:72-83, 1960.
12. Katlus, A. A. (Chrmn.) Exercise testing and training of apparently healthy individuals: A handbook for physicians. The Committee on Exercise American Heart Association. 1972.
13. Klein, K. E., H. Bruner, D. Jovy, L. Vogt, and H. M. Wegmann. The influence of stature and physical fitness on tilt-table and acceleration tolerance. *Aerospace Med.* 40:293-297, 1969.
14. Maxfield, M. E., H. C. Bazett and C. C. Chambers. Seasonal and postural changes in blood volume. *Am. J. Physiol.* 133:128-154, 1941.
15. Meehan, J. P., and H. I. Jacobs. Relation of several physiological parameters to positive G tolerance. WADC TR-58-665, 1959.
16. Miller, P. B., R. L. Johnson, and L. E. Lamb. Effects of four weeks of absolute bedrest on circulatory functions in man. *Aerospace Med.* 35:1194-1200, 1964.
17. Murray, J., and P. V. Darpovich. Weight Training in Athletics. Prentice Hall, Inc.; 1956.
18. Myhre, L. G., D. K. Brown, F. G. Hall, and D. B. Dill. The use of carbon monoxide and T-1824 for determining blood volume. *Clin. Chem.* 14:1197-1205, 1968.
19. Nash, P. R. Loss of consciousness in high performance fighters. *Aerospace Safety* 35:6-7. 1979.
20. Oscai, L. B., B. T. Williams, and B. A. Hertig. Effect of exercise on blood volume. *J. Appl. Physiol.* 24:622-624, 1968.
21. Pearson, R. G., and G. E. Byars, Jr. The development and validation of a check list for measuring subjective fatigue. SAM-TR-56-115, 1956.
22. Rasch, P. J. Weight Training. Wm. C. Brown Co.; 1966.
23. Shaffstall, R. M., and R. R. Burton. Evaluation of assisted positive pressure breathing on $+G_z$ tolerance. *Aviat. Space Environ. Med.* 50:820-824, 1979.
24. Spealman, C. R., M. Newton, and R. L. Post. Influence of environmental temperatures and posture on volume and composition of the blood. *Am. J. Physiol.* 150:628-640, 1947.
25. Taylor, A. W. The Scientific Basis of Sports Training. Charles W. Thomas; 1975.
26. Vasil'yev, P. V., and A. R. Kotovskaya. Effect of long term linear and radial acceleration on the organism. Foundation of Space Biology and Medicine. Moscow, USSR: Acad. of Sci. and Washington, DC: NASA TT-F-14, 841; p. 44. 1973.
27. Wessel, J. A. An investigation of the relation between man's fitness for strenuous work on his ability to withstand high headward acceleration. Ph.D. Dissertation. Univ. of Southern California Library, 1950.